A SYSTEM OF SYSTEMS APPROACH FOR MARTIAN EXPLORATION.

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Introduction: Future Mars exploration will require a systematic approach to ensure mission success and smooth the way for human exploration and colonization. The Mars Exploration Program Analysis Group (MEPAG) has determined a set of objectives which define the priorities for Martian exploration. It is impractical to meet all of the MEPAG objectives in a single mission. Instead, a system of systems will be designed to focus on a small, feasible selection of the objectives.

Goals and Objectives: Prior to human exploration and colonization of Mars, an in depth characterization of the planet's current atmosphere must be made, as well as an understanding of the nature and evolution of geologic processes that formed the planet. For this reason, two MEPAG objectives were chosen as the focus of this system.

MEPAG Goal II Objective A. Characterize Mars' atmosphere, present climate, and climate processes under current orbital configuration.

MEPAG Goal III Objective A. Determine the nature and evolution of the geologic processes that have created and modified the Martian crust.

These specific objectives have led to a system of systems design approach that is feasible for the 2026 launch opportunity. This system of systems is composed of a Lander, several Super Pressure (SP) Balloons and many Guided Delivery Vehicles (GDVs) carrying exploration Microbots, as seen in Figure 1.

Satisfying MEPAG Goal II Objective A, the Lander will launch tethered SP Balloons that will characterize the atmosphere at various altitudes above the Lander, while simultaneously acting as a communications relay. The Lander will provide power to the SP Balloon through a conducting Carbon Nano-Tube tether, as well as collect atmospheric data in its surrounding environment.

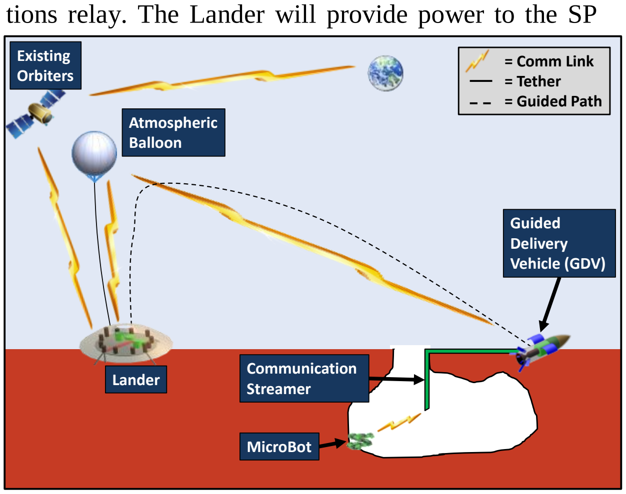

Figure 1: Concept of Operations

A Microbot snake deployed from a GDV will explore existing lava tubes through skylights, to collect data in support of Satisfying MEPAG Goal III Objective A. The Lander will also collect geological data in its surrounding environment.

Location: A small area in the Tharsis region is chosen as the landing site for this mission due to its high concentration of candidate skylight lava tube entrances, as seen in Figure 2. The candidate skylight entrances are indicated by red stars. The ring surrounding the skylights represents a range capability predicted for the GDVs.

Mission Requirements: From the MEPAG Goals and Objectives, high level mission requirements are derived and implemented into the design, and are as follows:

- Remain operational for a minimum of one Martian year for adequate seasonal data
- Conduct high altitude Entry, Descent and Landing (EDL)
- Conduct multiple sorties for science measurements at several locations
- Communicate data to and from Earth
- Compatible with current launch vehicles and aeroshells
- Operate with a high level of autonomy, and operate in a GPS denied environment
- Meet a 2026 launch opportunity

System Design Proposal: A system of systems design provides redundancy through multiple expendable and deployable sensor packages. The Lander and SP Balloon will remain operational for one Martian year. The GDVs and Microbots can investigate multiple Areas of Interest (AoI) in parallel or in series as new science data becomes available from earlier AoIs.

Lander. The Lander will provide safe delivery of the mission payload to the proposed landing site, where it will operate as a communication link to Earth, through existing Mars orbiters. The Lander will be capable of scientific measurements in support of the MEPAG Goals and Objectives. The Lander will house several SP Balloons and many GDVs, with the capability to deploy each via a command from Earth. Power for the tethered SP Balloon, as well as the Lander's onboard instrumentation and heating will be powered by a Radio Isotope Generator (RTG).

Super Pressure Balloon. The SP Balloon will measure the wind, temperature, density and composi-

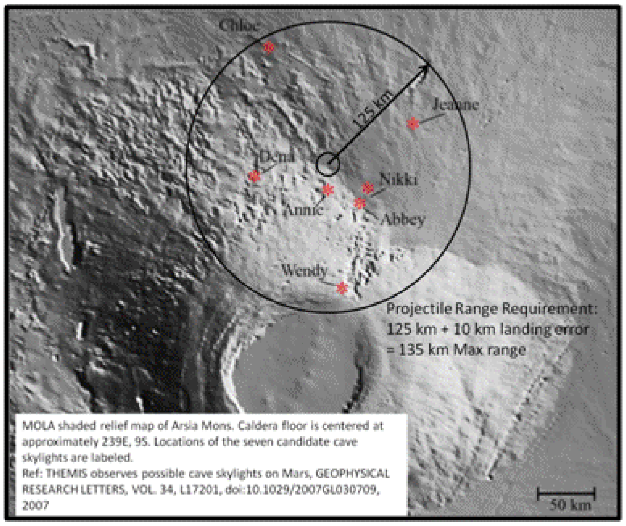

Figure 2: Proposed Landing Location

tion of the atmosphere at various altitudes. A light weight composite balloon skin, and light weight conducting Carbon Nanotube tether (used to provide power to the balloon instrumentation and communication devices) will increase payload capability or reduce the size. The balloon also simultaneously acts as a communication relay to any launched and active GDVs. Several SP Balloons will provide system redundancy and increase the operational lifetime of the system.

Guided Delivery Vehicle. The GDV will provide safe delivery of the Microbot to the proposed lava tube skylights. The GDV will provide line-of-sight (LOS) communications to the SP Balloon, acting as a communication relay from the Microbot to the tethered SP Balloon. The GDVs will launch vertically from the Lander using a solid rocket motor, and employing blowout doors on the top and bottom of the Lander. Upon launch, wings and fins will be deployed for vehicle control and a lifting trajectory to extend range. The GDV will employ a parachute, and house an airbag and crumple zone on the nose to reduce impact accelerations upon landing. The capability to launch multiple GDVs provides system redundancy, and allows *in situ* exploration of multiple lava tubes.

Microbot. The Microbot will be a snake-like robot design, providing autonomous cave exploration of unknown terrain in a GPS denied environment. Once the GDV has landed near the skylight, the Microbot will deploy and traverse to the skylight entrance, while deploying a ruggedized fiber optic line from a detachable section. The Microbot will tow the fiber optic line through the lava tube skylight before detaching and falling into the lava tube for cave exploration. The fiber optic line is attached to the GDV and will will overhang into the skylight after detachment from the Microbot, providing LOS Bluetooth communications to the Microbot, and fiber optic communications to the GDV. The Microbot will collect visual and infrared imagery, and conduct gas spectroscopy in support of MEPAG Goal II Objective A. The Microbot is a modular design with interlocking links. Each link contains a payload bay, containing instrumentation, batteries, avionics or communications. By varying the links, the Microbot can be optimized for different exploration missions and mission endurances.

A concept for a Van der Waals force “snake-skin” is proposed for the Microbot. This is a low Technology Readiness Level (TRL) technology, but results in increased capability in cave exploration.

Technology Roadmap: Redundancy and extensive use of legacy systems (e.g. Bluetooth, EDL, launch vehicles, aero shells, ALE-55, etc.) enhance the probability of mission success. The following risk mitigation strategies and technology development paths are integrated into the system design:

- Redundant and modular link approach enhances Microbot capability and versatility
- Several SP Balloons and many GDVs promotes successful data return to Earth
- Multiple similar and modular payloads reduce packaging complexity
- Utilization of legacy EDL techniques and lessons learned promotes successful system deployment
- Impact load reduction techniques integrated into GDV and high g-load Microbot design reduce risk of damage upon GDV landing
- Large control surfaces and significant testing bolster GDV landing precision
- Early investment and technology tracking will encourage successful development of Van der Waals force snake skin
- Significant investment and testing in Carbon Nanotube technology will reduce tether risk
- Standard systems engineering practices will increase the likelihood of mission success

Summary: There are four primary advantages to the proposed system of systems approach to Mars exploration. The proposed Mars exploration system was designed to accomplish multiple MEPAG objectives in a single mission. The vehicles that make up this system maximize value to the science community. To maximize the robustness of the system, the vehicle configurations have minimal sensitivity to the largest variations in the Mars environment, namely the atmosphere. Multiple expendable deployable sensor packages ensure that mission requirements can be met with a high level of redundancy. The proposed concept is feasible for the 2026 launch opportunity.